Managing Spent Fuel and Nuclear Waste Successfully – What Needs to Be Done?

Testimony to the Blue-Ribbon Commission on the Nuclear Future

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Mr. Chairman, members of the Commission, it is an honor to be here today to discuss a very important subject – how the United States can move forward in managing the back end of the nuclear fuel cycle. This is a topic that affects the world's energy future; safety and environmental protection; cost; and security from terrorism and nuclear proliferation.

I want to make six main points today.

1. The key to success is rebuilding public trust, through a voluntary, democratic process.

First, the key to success in managing spent fuel and nuclear waste is to regain public trust and achieve public acceptance of the necessary facilities. This will require processes that are voluntary, open, democratic, and focused on building trust. Fundamentally, this is more a political and institutional question than a technical one. If we succeeded in building public trust and gaining support for siting spent fuel and nuclear waste storage and disposal facilities, but never developed any technology beyond what is available today, we would have a reasonably successful nuclear waste management program. But if we fail in rebuilding public trust, we will have paralysis, escalating costs, major uncertainty over new reactor construction, and accumulating risks, even if we succeed in developing a range of new nuclear technologies. This Commission's most important mission, therefore, is to lay out a political and institutional approach that can succeed in rebuilding public trust, severely damaged by decades of failure in this area. As any approach will take decades to implement, political sustainability is key, which requires building long-term bipartisan consensus; without bipartisan support, the probability of failure is high. I recommend that the Commission establish a fourth subcommittee, focused on processes, siting, and public trust.

Both Finland and Sweden have recently succeeded in choosing sites for permanent geologic nuclear waste repositories *with* strong support from the local communities.[1] (In Finland, the community that did *not* get the repository sued.) They began with a fundamental principle, enacted in law: no community would be forced to accept a repository it did not want. They then established nuclear waste organizations that undertook careful, open, and transparent processes that considered a number of different potential sites, made sure everyone in each community had the opportunity to be fully informed and to offer their views, and focused on building trust – in particular, by building a reputation for delivering on commitments made to each community, step-by-step. The communities received benefits for being considered, and more for accepting a repository – but they made certain to build public trust before talking about how much communities might receive.[2] In both cases, the communities chosen were

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[1] For a useful discussion of the Finnish experience, see Juhani Vira, "Winning Citizen Trust: The Siting of a Nuclear Waste Facility in Eurajoki, Finland," and Allison Macfarlane, "Is it Possible to Solve the Nuclear Waste Problem?" *Innovations: Technology, Governance, Globalization,* Vol. 1, No. 4 (Fall 2006), pp. 67-82 and pp. 83-92.

[2] In a range of studies, it has been found that offering to pay communities *without* first building trust can actually

communities where nuclear reactors were located, whose residents were already comfortable with nuclear power, used to the jobs and tax revenue such facilities brought in, and aware that there was spent fuel in surface storage in their community that needed to be addressed. We should learn from their example. I recommend that the Commission travel to Finland and Sweden to learn about the approach these countries have taken first hand.

In 2001, with colleagues from the University of Tokyo, my colleagues at Harvard and I published a detailed study on interim storage of spent nuclear fuel, which examined the political history of spent fuel management in Japan and the United States and recommended an open, democratic approach to siting facilities based on the "facility siting credo." The credo had been developed drawing on the experience of a wide range of successful and unsuccessful efforts to site a variety of unwanted facilities.[3] I believe the modified credo we developed remains fundamental to moving forward in siting either centralized spent fuel storage facilities or a geologic nuclear waste repository. The key elements of the modified credo we proposed are presented in Table 1.

Table 1: A Modified Facility Siting Credo

- Achieve agreement that a facility is needed, that the status quo without it is unacceptable

Procedural Steps

- Institute a broad-based participatory process
- Seek consensus
- Work to develop trust
- Seek acceptable sites through a volunteer process
- Consider competitive siting processes
- Set realistic timetables ("go slowly in order to go fast")
- Keep multiple options open

Desired Outcomes

- Choose the storage approaches and sites that best address the problem
- Guarantee that stringent safety standards will be met
- Build confidence that storage will be temporary (in the case of interim storage facilities) and permanent solutions forthcoming

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undermine public support, by leading people to believe you are asking them to sell their fundamental rights. For a particularly interesting discussion of this phenomenon in a different context – negotiations over Middle East peace – see Jeremy Ginges, Scott Atran, Douglas Medlin, and Khalil Shikaki, "Sacred Bounds on Rational Resolution of Violent Political Conflict," *Proceedings of the National Academy of Sciences,* Vol. 104, No. 18, 1 May 2007, pp. 7357-7360.

[3] Matthew Bunn, John P. Holdren, Allison Macfarlane, Susan E. Pickett, Atsuyuki Suzuki, Tatsujiro Suzuki, and Jennifer Weeks, *Interim Storage of Spent Nuclear Fuel: A Safe, Flexible, and Cost-Effective Approach to Spent Fuel Management* (Cambridge, MA: Project on Managing the Atom, Harvard University, and Project on Sociotechnics of Nuclear Energy, University of Tokyo, June 2001), pp. 87-116. For an early discussion of the facility siting credo, see Howard Kunreuther, Kevin Fitzgerald, and Thomas D. Aarts, "Siting Noxious Facilities: A Test of the Facility Siting Credo," *Risk Analysis*, Vol. 13, No. 3 (1993), pp. 301-331.

- Fully address all negative aspects of the facility
- Make the host community better off
- Use contingent agreements (specifying what happens if something goes wrong)
- Work for geographic fairness

We should not underestimate the difficulty of building public trust in the management of nuclear waste in the United States. A long and unpleasant history has made many members of the public justifiably distrustful of everything the Department of Energy (DOE) tells them about safe management of nuclear materials; DOE starts with a major trust deficit. The commission should at least consider whether a different institution should be given this responsibility, which can start over from scratch in the trust-building process. (The clear counter-example is the success of the Waste Isolation Pilot Plant (WIPP) in New Mexico: after initial controversies and protests over the first few shipments, WIPP operation has become routine, and has the support of most people in the local community.) I do not have a specific institutional recommendation, but it is worth considering whether it makes sense to put more of the responsibility and the resources for developing and implementing safe, secure, and cost-effective storage, management, and disposal approaches in the hands of the states and utilities that have spent fuel and nuclear wastes that need to be managed.[4] In particular, I believe the annual payments to the Nuclear Waste Fund should ultimately go directly to the institution or institutions charged with managing these wastes, without requiring congressional appropriation; the current approach, in which less is appropriated than is collected every year, and the appropriations are always subject to the uncertainties of politics on Capitol Hill, has delayed progress and relies heavily on the questionable assumption that future Congresses will be willing to add to future deficits to pay back the "borrowing" from the nuclear waste fund that the country is doing today.

It seems inevitable, with the cancellation of the Yucca Mountain repository, that far-reaching amendments to the Nuclear Waste Policy Act will be required. Among other things, steps will be required to address the long-broken promise that DOE would begin taking the utilities' spent fuel in 1998. I recommend that the Commission develop a comprehensive, integrated approach to such amendments that incorporates a voluntary, democratic process and that addresses all the types of spent nuclear fuel and high-level waste that the United States will have to manage, taking political sustainability, cost, safety, environmental protection, terrorism resistance, proliferation risk, and ability to support a potentially growing nuclear enterprise for the long term into account in a balanced way.

As part of the process of building public trust, the United States needs a different approach to performance standards for geologic repositories and assessments of whether they are met. There should probably be a single, generic standard, rather than a site-specific standard. And given how difficult it is to understand and defend detailed numerical calculations of performance hundreds of thousands of years in the future, the emphasis on such calculations should be reduced, incorporating expanded reliance on qualitative judgments and natural analogs.

2. We have time; we should not rush to judgment or lock in technological choices prematurely.

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[4] See, for example, Rodney C. Ewing and Frank von Hippel, "Nuclear Waste Management in the United States – Starting Over," *Science*, Vol. 325, 10 July 2009, pp. 151-152.

Second, we have time, and we should use it, avoiding a rush to judgment or pathways that lock in technological choices that may turn out to be the wrong ones. Spent fuel can be stored safely, securely, and cheaply for decades in dry casks, leaving all options open for the future, and allowing time for the economic, technical, and political issues on all paths to be more fully explored. From Clinch River to Wackersdorf, from Chernobyl to the Hanford tanks, the nuclear age is littered with the costly results of the rushed decisions of the past. Rushing to make decisions before the needed analyses and R&D are completed will leave us with programs that are more costly and less effective than they could otherwise be.

Hence, we should focus first on safe, secure, and politically sustainable approaches to interim storage of spent fuel. These will be needed no matter what long-term options we choose for spent fuel management; if properly implemented, they will address the immediate needs of the nuclear industry and provide the confidence needed for construction of new reactors.

I recommend that the commission follow the advice of the bipartisan National Commission on Energy Policy, which, in the area of interim storage, concluded that the United States should:[5]

- Expand interim spent fuel storage capacities, including through legislation that would require the Department of Energy to establish at least limited consolidated national or regional storage facilities;
- Amend the Nuclear Waste Policy Act to make clear that interim storage and federal responsibility for waste disposal are sufficient to satisfy the Nuclear Regulatory Commission's waste confidence requirement; and
- Amend the act to require the Secretary of Energy to take possession of and/or remove fuel from decommissioned reactor sites.

We should resist the temptation to adopt processes that assume that we know today what the best choices will be decades in the future with respect to reprocessing and recycling or direct disposal of spent nuclear fuel. In particular, we should not, as has sometimes been proposed, follow processes in which centralized spent fuel storage facilities can only be established at sites that will also have reprocessing facilities. The Japanese experience – in which the utilities had promised local communities that spent fuel would be sent away from the reactors, and the government forbid sending it anywhere but a reprocessing plant, forcing them to go forward with a reprocessing plant even as its costs skyrocketed and prospects for reactors that would use the plutonium dwindled – is one we should not be eager to repeat. Similarly, in Britain, with extensive forward contracts paying for the construction of a reprocessing plant, the facility developed an unstoppable institutional momentum even as it began to make less and less economic sense; ultimately, this experience led to the effective destruction of British Nuclear Fuels, Limited (BNFL), and billions of dollars in excess costs to the British taxpayers for a facility that has been plagued with problems throughout its life.[6]

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[5] National Commission on Energy Policy, *Energy Policy Recommendations to the President and 110th Congress* (Washington, D.C.: National Commission on Energy Policy, April 2007), pp. 18-19. See also National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges* (Washington, D.C.: National Commission on Energy Policy, December 2004), pp. 60-61.

[6] For a discussion of the Japanese experience, see Bunn et al., *Interim Storage of Spent Nuclear Fuel*, pp. 34-45. For a useful discussion of the British experience, see William Walker, *Nuclear Entrapment: THORP and the*

Along the same lines, we should not today designate spent fuel as a "resource." Some certainly see it as a resource, others as a waste. There is no need to resolve that debate today to make the decisions needed to move forward. Spent fuel today is like oil shale: there is energy there, but the cost of getting that energy out is more than the energy is worth in today's market. (The difference is that in the case of spent fuel, getting the energy out involves substantial risks as well as costs, as discussed below.) Indeed, today, a utility that had a stock of already reprocessed plutonium – for which the costs of reprocessing were already paid – would have to carry this material on the "liability" rather than the "asset" side of the ledger, as the price of fabricating it into fuel is more than the value of the fuel.

Our generation does have a responsibility to future generations to set aside sufficient funds to manage spent fuel and nuclear wastes in the future, and to establish R&D programs and institutional processes that will maximize the chance that they will have attractive options to choose from when the time comes. But future generations will not thank us for rushing to judgment in choosing one path prematurely, depriving them of what might turn out to be better options developed later. Indeed, because most repository concepts would keep the site open for 50-100 years, with the spent fuel readily retrievable, moving forward with direct disposal of spent nuclear fuel would still leave all options open for decades to come.

3. *We will need a permanent geologic waste repository no matter what nuclear fuel cycle options we pursue.*

Third, we will need a nuclear waste repository whether we reprocess or not. All spent fuel management approaches will, in the end, leave nuclear wastes that will require a repository for safe disposal. Moreover, the wide variety of high-level wastes and spent fuels already in the Department of Energy's inventory will require repository disposal regardless of what the United States ultimately does with commercial spent nuclear fuels. And realistically, even if, decades from now, the United States decides to begin reprocessing and recycling spent nuclear fuel, it seems unlikely that all of the commercial spent nuclear fuel already generated will be reprocessed. One way or another, it is very likely that a repository will be accepting large quantities of unreprocessed spent nuclear fuel, and future repositories should be designed with the flexibility to handle either spent nuclear fuel or reprocessing wastes – to avoid prematurely locking in to one path, as discussed earlier.

While the first focus should be on interim storage, it is very important that the United States not simply put geologic repositories on an indefinite back burner. In particular, a public perception that the country is making credible progress toward permanent solutions – so that interim storage sites need not be considered permanent waste dumps – is likely to be quite important to success in siting centralized interim storage facilities. Generating that public perception will require a credible repository program that appears to be moving forward in a sensible way.

In considering approaches to a future repository (or repositories), the United States should again draw on the experience of other countries and consider the possibilities of chemically reducing sites such as the granite locations chosen in Finland and Sweden, or the clay sites being considered in several other countries, rather than oxidizing and geologically complex sites such as Yucca Mountain. At geologically simpler sites, there will be more prospect for

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Politics of Commitment (London: Institute for Public Policy Research, 1999).

making the safety case in ways that affected publics can understand, increasing the prospects for building public trust.

4. *Reprocessing with existing or near-term technologies poses high costs and risks and few benefits.*

Fourth, reprocessing and recycling U.S. spent fuel with the technologies we know how to implement today, or the technologies in prospect for the next decade or two, would be a costly mistake.[7] Nuclear power's future will be best if it can be made as cheap, as safe, as proliferation-resistant, as terrorism-resistant, as simple, and as uncontroversial as possible. Reprocessing using the technologies available in the near term points in the wrong direction on every count. Those who hope for a bright future for nuclear energy, therefore, should oppose near-term reprocessing of spent nuclear fuel.

Cost

Reprocessing using technologies available now or in the near term is likely to be substantially more expensive than direct disposal of spent fuel.[8] The UREX+ technology now being pursued adds a number of complex separation steps to the traditional PUREX process, and is likely to be even more expensive. While spent fuel management is only a small part of the cost of nuclear energy, advanced recycling would also require construction of a large fleet of fast reactors whose capital costs – the key driver of nuclear energy costs – have always been higher than those of light-water reactors. A National Academy of Sciences review of separations and transmutation technologies such as those proposed for GNEP concluded that the additional cost of recycling compared to once through for 62,000 tons of commercial spent fuel "is likely to be no less than $50 billion and easily could be over $100 billion."[9] Who will pay these costs? Are we talking about many decades of government subsidies, drastic increases in the nuclear waste fee, or onerous regulations requiring private industry to pay for uneconomic activities?

Some recent studies have offered the hope that somehow a new reprocessing and fuel fabrication plant in the United States would have per-kilogram costs far lower than those that have ever been demonstrated in practice.[10] But the real experience of building a plant similar to

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[7] For a useful recent discussion, see Frank von Hippel, *Managing Spent Fuel in the United States: The Illogic of Reprocessing* (Princeton: International Panel on Fissile Materials, January 2007).

[8] Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel* (Cambridge, MA: Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 2003), http://www.belfercenter.org/files/repro-report.pdf (accessed 20 May 2010). For quite similar conclusions, see John Deutch and Ernest J. Moniz, co-chairs, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, MA: Massachusetts Institute of Technology, 2003) http://web.mit.edu/nuclearpower/ (accessed 20 May 2010). For a study for the French government, see Jean-Michel Charpin, Benjamin Dessus, and René Pellat, *Economic Forecast Study of the Nuclear Power Option* (Paris, France: Office of the Prime Minister, July 2000) http://fire.pppl.gov/eu_fr_fission_plan.pdf (accessed 20 May 2010), Appendix 1. In Japan, the official estimate is that reprocessing and recycling will cost more than $100 billion over the next several decades, and the utilities have successfully demanded that the government impose an additional charge on all electricity users to pay the extra costs.

[9] U.S. National Research Council, Committee on Separations Technology and Transmutation Systems, *Nuclear Wastes: Technologies For Separation and Transmutation* (Washington, D.C.: National Academy Press, 1996), p. 7. Note that these figures are expressed in 1992 dollars; in 2010 dollars, the range would be $73-$145 billion.

[10] See, for example, Boston Consulting Group, *Economic Assessment of Used Nuclear Fuel Management in the United States* (Boston, Mass: BCG, July 2006). Similar claims have been made for pyroprocessing technologies,

the French reprocessing plant in Japan has been unit costs several times *higher* than those in France, not lower; the costs of the MOX fuel plant private firms are building for DOE, also based on French technology, are also several times *higher*, not lower, than those of the French plants. One can argue – correctly – that each of these new plants has unique problems, but why should we expect that a new reprocessing plant in the United States would avoid similar problems? No policy-maker should make decisions about reprocessing based on an expectation that the costs will be far lower than those that have ever been demonstrated before.

Rather than relying solely on paper analyses, one can look at the evidence from the commercial market. The British reprocessing plant will be closed in a few years because it cannot get enough contracts to keep running; the French and Russian reprocessing plants are operating at far less than capacity because of a lack of contracts; to pay the huge costs of the Japanese reprocessing plant, Japanese utilities insisted on a government bailout in the form of a wires charge that will increase the price of electricity for *all* users in Japan for many years to come – and the plant continues to struggle to operate, facing major problems in its waste vitrification system among other issues. In the French case, often cited as the most successful, the official government assessment is that reprocessing and recycling has cost many billions of dollars more than had it never been done. Some say the United States needs to move toward reprocessing to reestablish U.S. leadership in nuclear energy. But it is not leadership to be among the last to join a declining industry. When utilities have a choice, they do not choose to reprocess their fuel.

Proliferation Risks

Reprocessing and recycling using the only technologies now commercially available means separating, fabricating, and transporting tons of weapons-usable plutonium every year – when even a few kilograms is enough for a bomb. Though there has been major progress in safeguards and security technologies in recent decades, and some of the facilities that manage civilian plutonium are well guarded, this inevitably raises risks of nuclear proliferation and nuclear terrorism *not* posed by direct disposal. (It is crucial to understand that, as U.S. government studies have shown, any state or group that could make a bomb from weapon-grade plutonium could also make a bomb from the reactor-grade plutonium separated by reprocessing.[11]) Nearly all of the confirmed cases of theft of plutonium or highly-enriched uranium (HEU) have involved bulk materials, which are easier to squirrel away a little at a time, suggesting that we should make every effort to reduce, rather than expanding, the number of places that process these materials in bulk form; the other most vulnerable part of the life cycle of nuclear material is when weapons-usable material is being transported from place to place and might be forcibly hijacked – and that is also underway on a large scale with today's approaches

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but a recent multi-lab assessment of fuel cycle costs estimated that the per-kilogram costs of both pyroprocessing and fuel fabrication for that system would be *higher* than for traditional reprocessing and recycling approaches. See D.E. Shropshire, K.A. Williams, W.B. Boore, J.D. Smith, B.W. Dixon, M. Dunzik-Gougar, R.D. Adams, and D. Gombert, *Advanced Fuel Cycle Cost Basis*, INL/EXT-07-12107 (Idaho Falls: Idaho National Engineering Laboratory, April 2007).

[11] For an authoritative unclassified discussion, see *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives*, DOE/NN-0007 (Washington DC: U.S. Department of Energy, January 1997), pp. 38-39. It is also worth noting that in many fast-reactor fuel cycles, the plutonium produced would be weapon-grade.

to reprocessing and recycling, with a truckload of plutonium on the road nearly every week in France, for example.

No country engaged in large-scale reprocessing has managed to keep pace in fabricating this material into fuel and avoid building up huge stockpiles separated plutonium. Remarkably, the stockpile of plutonium separated from spent fuel in civilian stores around the world is roughly as large (and possibly larger) as the amount in all the world's military stockpiles combined – enough for tens of thousands of nuclear weapons. The Bush administration, despite its enthusiasm for reprocessing, acknowledged that these growing stockpiles of civil plutonium "pose a growing proliferation risk" that "simply must be dealt with."[12]

Advocates argue that spent fuel processing technologies now being developed would be "proliferation resistant." But the approaches available in the next couple of decades would still pose significantly higher proliferation risks than *not* processing the spent fuel.

In the Bush administration, for example, a process sometimes known as "COEX" was considered, in which plutonium and uranium would be extracted from spent fuel together. This offers little proliferation-resistance benefit. As U.S. government examinations of the question have concluded, nuclear explosives could still be made directly from the roughly 50-50 plutonium-uranium mixes that COEX advocates refer to, though the quantity of material required for a bomb would be significantly larger. Moreover, any state or group with the capability to do the difficult job of designing and building an implosion-type bomb from pure plutonium would have a good chance of being able to accomplish the simpler job of separating pure plutonium from such a plutonium-uranium mix. The job could be done in a simple glove-box with commercially available equipment and chemicals, using any one of a number of straightforward, published processes. For these reasons, under either U.S. or international guidelines, such a mixture would still be considered Category I material, posing the highest levels of security risk and requiring the highest levels of security. When such approaches were last seriously considered in the United States three decades ago, the Nuclear Regulatory Commission concluded that "lowering the concentration of plutonium through blending [with uranium] should not be used as a basis for reducing the level of safeguards protection," and that the concentration of plutonium in the blend would have to be reduced to ten percent or less – far less than being considered for COEX – for the safeguards advantages to be "significant."[13] The Bush administration's repeated statement that these processes would result in "no pure plutonium" was a slogan, not a serious analysis of proliferation and security impacts.

Advocates argue that approaches such as UREX+ would be more proliferation-resistant, because the minor actinides (and perhaps a few of the lanthanide fission products) would remain with the plutonium, making the separated product more radioactive and more problematic to

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[12] Secretary of Energy Samuel Bodman, "Carnegie Endowment for International Peace Moscow Center: Remarks as Prepared for Secretary Bodman," 16 March 2006 http://moscow.usembassy.gov/transcript-31.html (accessed 20 May 2010). In a similar vein, the British Royal Society, in a 1998 report, warned that even in an advanced industrial state like the United Kingdom, the possibility that plutonium stocks might be "accessed for illicit weapons production is of extreme concern." The Royal Society, *Management of Separated Plutonium* (London: Royal Society, 1998), http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5918 (accessed 20 May 2010).

[13] Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, *Safeguarding a Domestic Mixed Oxide Industry against a Hypothetical Subnational Threat*, NUREG-0414 (Washington, D.C.: NRC, 1978), pp. 6.8-6.10.

steal and process into a bomb.[14] UREX+ facilities could be designed so that modifying them to separate pure plutonium would be moderately costly and readily observable. But the processing proposed in UREX+ still takes away the great mass of the uranium and the vast majority of the radiation from the fission products, making the process far less proliferation-resistant than simply leaving the plutonium in the spent fuel. Indeed, the plutonium-bearing materials that would be separated in either the UREX+ process or by pyroprocessing would not be remotely radioactive enough to meet international standards for being "self-protecting" against possible theft.[15] Non-nuclear-weapon states that built and operated UREX+ facilities would gain experience, infrastructure, and materials that would allow them to produce plutonium for nuclear weapons more rapidly and at less cost. For these reasons, the State Department has publicly expressed the view that UREX+ facilities, like PUREX facilities that separate pure plutonium, must remain "forever confined" to a small number of supplier states.[16] That is a challenging objective, which will be made more difficult by the United States emphasizing the importance of reprocessing.

The case of pyroprocessing approaches is somewhat similar. Such systems are designed to leave some of the actinides and fission products with the plutonium, making the material less attractive for theft and diversion. If, as is proposed in some concepts, all operations were done remotely behind thick radiation-protection walls, with no human access to the material at any time, the risk of nuclear theft would be lower than it is when plutonium is simply separated and put into cans that can be handled by hand. But non-nuclear-weapon states operating pyroprocessing facilities would gain infrastructure for and expertise in chemically processing intensely radioactive spent fuel, along with in-depth experience with plutonium processing and metallurgy, all of which would be very helpful to a nuclear weapons program. The United States should understand that pyroprocessing is a form of reprocessing, and the United States should oppose the spread of this technology to additional countries just as it opposes the spread of aqueous reprocessing technologies. (The South Korean case, in particular, is discussed in more detail below.)

Another difficulty is that these "proliferation-resistant" processes may make high-confidence international safeguards more difficult. Nuclear material accounting for safeguards is already an immense challenge at traditional PUREX reprocessing plants that separate pure plutonium, with accounting uncertainties in the range of 1 percent at plants processing 6-10 tons of plutonium every year. By keeping a variety of radioactive materials with the plutonium,

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[14] Of all the various impacts of civilian nuclear energy on proliferation, this would *only* help with respect to the difficulty of theft of the separated material and processing it into a bomb: while that is not unimportant, many other issues should be considered in assessing proliferation resistance of a nuclear energy system, particularly as there has never yet been an historical case in which the radiation level of the material involved was the key in determining the civilian nuclear system's impact on proliferation outcomes. For a discussion of broader issues that should be considered in assessing proliferation-resistance, and rough measures for assessing them, see Matthew Bunn, "Proliferation-Resistance (and Terror-Resistance) of Nuclear Energy Systems" lecture, Massachusetts Institute of Technology, 20 November 2007, http://belfercenter.ksg.harvard.edu/files/bunn_proliferation_resistance_lecture.pdf (accessed 20 May 2010)

[15] See Jungmin Kang and Frank von Hippel, "Limited Proliferation-Resistance Benefits From Recycling Unseparated Transuranics and Lanthanides From Light-Water Reactor Spent Fuel," *Science and Global Security,* Vol. 13, pp. 169-181, 2005, http://www.princeton.edu/sgs/publications/sgs/pdf/13_3%20Kang%20vonhippel.pdf (accessed 20 May 2010).

[16] James Timbie, U.S. Department of State, remarks to an open meeting of the U.S. National Academy of Sciences-Russian Academy of Sciences Committee on Internationalization of the Nuclear Fuel Cycle, 17 October 2006.

UREX+ and pyroprocessing approaches will make accurate nuclear material accounting for safeguards substantially *more* difficult. Hence they will require much greater reliance on containment and surveillance.[17]

Proponents of reprocessing and recycling often argue that this approach will provide a nonproliferation benefit by consuming the plutonium in spent fuel, which would otherwise turn geologic repositories into potential plutonium mines many hundreds or thousands of years in the future. But the proliferation risk posed by spent fuel buried in a safeguarded repository is already modest; if the world could be brought to a state in which such repositories were the most significant remaining proliferation risk, that would be cause for great celebration. Moreover, this risk will be occurring a century or more from now, and if there is one thing we know about the nuclear world a century hence, it is that we know almost nothing about it. We should not increase significant proliferation risks in the near term in order to reduce already small and highly uncertain proliferation risks in the distant future.[18]

In short, all of the spent fuel processing approaches proposed likely to be available in the near term pose higher, not lower, proliferation risks than are posed by not processing the spent fuel at all and continuing to rely on a once-through fuel cycle. Some of these approaches do offer modest proliferation advantages compared to the traditional PUREX reprocessing approach. But there are no grounds for confidence that our pursuit of these technologies will convince other countries to phase out the PUREX processes in which they have made large investments, particularly as processes such as UREX+ add several complex steps and are therefore likely to be more expensive.

Ultimately, proliferation resistance should not be judged solely on how much material other than plutonium there may be in the product of a particular process, or how radioactive that product might be. Rather, it should be judged by a full life-cycle examination of how the deployment of such technologies by some states might affect the spread of sensitive technologies to other states; how much access to the materials, facilities, and expertise involved in the proposed fuel cycle would reduce the time, cost, and observability of a state nuclear weapons program; and how the large-scale adoption of such a fuel cycle would affect the risks of nuclear theft and nuclear terrorism around the world.[19]

With crises brewing over the nuclear programs of North Korea and Iran, and a variety of targets for nuclear theft that are more vulnerable than reprocessed plutonium at large facilities in developed countries is likely to be, the issues raised by civilian reprocessing are not among the world's highest proliferation risks. But they are real risks nonetheless, and running them is entirely unnecessary, given the availability of dry cask storage as a secure alternative.

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[17] For a discussion, see Edwin S. Lyman, "The Global Nuclear Energy Partnership: Will it Advance Nonproliferation or Undermine It?" in *Proceedings of the Institute for Nuclear Materials Management 47th Annual Meeting*, Nashville, Tennessee, 16-20 July 2006 (Northbrook, IL: INMM, 2006) http://www.npec-web.org/Essays/20060700-Lyman-GNEP.pdf (accessed 20 May 2010); see also von Hippel, *Managing Spent Fuel in the United States*, pp. 23-24.

[18] For a discussion, see John P. Holdren, "Nonproliferation Aspects of Geologic Repositories," presented at the "International Conference on Geologic Repositories," October 31-November 3, 1999, Denver, Colorado).

[19] For a discussion, see Matthew Bunn, "Proliferation-Resistance (and Terror-Resistance) of Nuclear Energy Systems." For a more elaborate methodology, see *Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems* (Paris: Gen. IV International Forum, November 2006 http://www.gen-4.org/Technology/horizontal/PRPPEM.pdf.

Safety And Security Risks

No complete life-cycle study of the safety and terrorism risks of reprocessing and recycling compared to those of direct disposal has yet been done by disinterested parties. But it seems clear that extensive processing of intensely radioactive spent fuel using volatile chemicals presents more opportunities for release of radionuclides – either by accident or by sabotage – than does leaving spent fuel untouched in thick metal or concrete casks.

While the safety record of the best reprocessing plants is good, it is worth remembering that until Chernobyl, the world's worst nuclear accident had been the explosion at the reprocessing plant at Khyshtym (site of what is now the Mayak Production Association) in 1957, and significant accidents occurred at both Russian and Japanese reprocessing plants as recently as the 1990s. The British THORP plant suffered a massive leak of radioactive acid solution in 2005 containing tens of tons of uranium and some 160 kilograms of plutonium, which had gone unnoticed for months (though none of this material ever left the plant, and there was no known radioactive release). The Japanese pilot reprocessing plant at Tokai suffered a fire and explosion in 1997, considered the worst nuclear accident in Japan up until that time, which resulted in modest radioactive releases.

Environmental Impact and Repository Space

Advocates sometimes argue that the major benefit of reprocessing and recycling will be in reducing the environmental impact of nuclear waste disposal, the size of the repositories that will ultimately be needed, or the political opposition to nuclear waste disposal.

In fact, estimated doses to humans and the environment from geologic disposal of spent fuel are already quite small, when compared to the risks per kilowatt-hour from many other energy technologies (or the other risks from nuclear energy). While the relevant studies have not yet been done, it seems very likely that if reducing environmental risks from the repository were the principal goal of recycling, the cost per life saved would be in the billions of dollars – and those possibly saved lives would be tens of thousands of years in the future. Moreover, the near-term environmental impacts of reprocessing and recycling (including fabrication, transport, and use of the proposed highly radioactive fuels), even when balanced in part by the reduction in the amount of uranium mining that would be required, are likely to overwhelm the possible long-term environmental benefit of reduced exposures from a geologic repository – though no credible study has yet been done comparing these risks for advanced recycling and once-through fuel cycles.

Reprocessing advocates often argue that reprocessing reduces the volume of high-level wastes to be disposed. This is true (discounting the volumes of intermediate and low-level waste generated by reprocessing), but irrelevant: the size and cost of repositories is not driven by the volume of material to be placed in them. In repositories like Yucca Mountain, it is driven by heat.

When Yucca Mountain was the planned repository, recycling advocates argued that no license would ever be granted for a second repository, and recycling would be essential to condensing all the wastes from decades of a growing future nuclear enterprise into Yucca Mountain.[20] By fissioning actinides that generate much of the long-term heat, advanced

[20] For a cogent version of this argument for recycling, see Per F. Peterson, "Will the United States Need a Second

recycling approaches could, *if* they succeeded in meeting a range of challenging technical objectives, make it possible to dramatically expand the capacity of the proposed Yucca Mountain repository.[21]

But this was always an issue largely confined to Yucca Mountain – a repository with fixed sides, where one could not just make the tunnels longer indefinitely to make the repository bigger. (Even there, the physical capacity almost certainly would have been dramatically larger than reprocessing advocates argued.[22]) Other sites – such as the huge zones of granite that have been chosen in Finland and Sweden, and similar locations under consideration in other countries – do not have this space limitation. A single repository site can be extended almost indefinitely, simply by making the tunnels longer. For this reason, measuring quantities of spent fuel in "Yucca Mountain equivalents" is highly misleading; if, in fact, a second repository is ever needed, it is unlikely that the nation will again make the mistake of choosing one that is not readily expandable.

Advocates of the environmental benefit of advanced recycling often argue that the chances for public acceptance of geologic repositories will be greatly improved by fissioning long-lived actinides and transmuting long-lived fission products, so that repositories would only need to perform with high effectiveness for hundreds of years, rather than hundreds of thousands of years. What this leaves out is the difficulty of gaining public and regulatory approval for the complex and expensive spent fuel processing and transmutation facilities needed to implement this approach – including scores of advanced burner reactors. That seems very likely to be as difficult as siting a geologic repository. Reprocessing of spent fuel has been fiercely opposed by a substantial section of the interested public in the United States for decades – and the real risks to neighbors from a large above-ground reprocessing plant performing daily processing of spent fuel are inevitably larger than those from nuclear wastes sitting quietly deep underground. Similarly, there seems little doubt that licensing and building the new reactor types required would be an enormous institutional and political challenge. It is worth noting that the two countries that have succeeded in gaining public approval for siting geologic repositories are countries that are planning direct disposal of spent fuel, not reprocessing.

Uranium supply

Many advocates of recycling point extending the uranium resource as a key rationale. As with environmental impact, traditional reprocessing with one round of MOX recycling has only very modest benefit in extending uranium resources. The amount of energy generated from each ton of uranium mined is increased by less than 20%.[23]

Repository?" *The Bridge*, Vol. 33, No. 3, pp. 26-32, Fall 2003.

[21] Roald A. Wigeland, Theodore H. Bauer, Thomas H. Fanning, and Edgar E. Morris, "Separations and Transmutation Criteria to Improve Utilization of a Geologic Repository," *Nuclear Technology*, Vol. 154, April 2006, pp. 95-106.

[22] *Program on Technology Innovation: Room at the Mountain – Analysis of the Maximum Disposal Capacity for Commercial Spent Nuclear Fuel in a Yucca Mountain Repository* (Palo Alto, Calif: Electric Power Research Institute, May 2006), http://www.epriweb.com/public/000000000001013523.pdf (accessed 20 May 2010). This study argued that Yucca Mountain could almost certainly hold over 260,000 tons of spent nuclear fuel, and might well be able to hold 570,000 tons or more. As the researchers concluded: "it is possible for Yucca Mountain to hold not only all the waste from the existing U.S. nuclear power plants, but also waste produced from a significantly expanded U.S. nuclear power plant fleet for at least several decades."

[23] Deutch and Moniz, The *Future of Nuclear Power*, p. 123. They present this result as uranium consumption per

Recycling and breeding in fast neutron reactors, by contrast, could potentially extend uranium resources dramatically. But world resources of uranium likely to be economically recoverable at prices far below the price at which reprocessing and breeding would be economic are sufficient to fuel a growing global nuclear enterprise for many decades, relying on direct disposal without recycling.[24] Indeed, even when uranium prices were too low to motivate much exploration, the "Red Book" estimates of world uranium resources were increasing far faster than uranium has been consumed[25] – and that trend is likely to accelerate substantially now that high prices are leading to far larger investments in uranium exploration. The more we look, the more uranium we are likely to find. Historically, the real price of most minerals has *declined* with both time and cumulative quantity extracted, as technology improved faster than resources were depleted, and the same is very likely to be true for uranium for decades to come.[26]

The recent run-up in uranium prices has nothing to do with a lack of resources in the ground, but only with constraints on bringing on new production to exploit those resources to meet market demand. When prices are well above production cost, there will be strong motivation to bring additional supplies on-line, and this process will eventually drive prices downward until supply and demand are in rough balance. This will be difficult to do quickly, because of regulatory and political constraints in uranium-producing countries. But it would be surprising indeed if the price remained far above the cost of production for decades.

Nor does reprocessing serve the goal of energy security, even for countries such as Japan, which have very limited domestic energy resources. If energy security means anything, it means that a country's energy supplies will not be disrupted by events beyond that country's control. Yet events completely out of the control of any individual country – such as a theft of poorly guarded plutonium on the other side of the world – could transform the politics of plutonium overnight and make major planned programs virtually impossible to carry out. Japan's experience following the scandal over BNFL's falsification of safety data on MOX fuel, and following the accidents at Monju and Tokai, all of which have delayed Japan's plutonium programs by many years, makes this point clear. If anything, plutonium recycling is much *more* vulnerable to external events than reliance on once-through use of uranium.

5. *We should manage the nuclear fuel cycle in the United States in a way that allows nuclear energy to grow and spread around the world while minimizing nuclear proliferation and terrorism risks.*

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kilowatt-hour being 15% less for the recycling case; equivalently, if uranium consumption is fixed, then electricity generation is 18% higher for the recycling case.

[24] For discussion, see "Appendix B: World Uranium Resources," in Bunn, Fetter, Holdren, and van der Zwaan, *The Economics of Reprocessing.*

[25] In 1997, the estimate for the sum of reasonably assured resources (RAR) and inferred resources $80/kgU or less was 3.085 million tons, while in 2005 it was 3.804 million tons, an increase of 23% in eight years, despite the very low level of investment in uranium exploration until the end of that period. See Organization for Economic Cooperation and Development, Nuclear Energy Agency, *Uranium 1997: Resources, Production, and Demand* (Paris: OECD-NEA, 1998), and *Uranium 2005: Resources, Production, and Demand* (Paris: OECD-NEA, 2006). Indeed, the press release for the 2005 edition was entitled: "Uranium: plenty to sustain growth of nuclear power." Estimated resources increased another 17% from 2005 to 2007 (as increased uranium prices drove more exploration), to 4.456 million tons.

[26] Erich A. Schneider and William C. Sailor, "Long-Term Uranium Supply Estimates," *Nuclear Technology,* Vol. 162 (June 2008), pp. 379-387.

The United States has a vital interest in strengthening the global effort to stem the spread of nuclear weapons and keep them out of terrorist hands – and in ensuring that the growth and spread of nuclear energy does not undermine those efforts.[27] Effective management of uranium enrichment and plutonium reprocessing – the two processes that make it possible to produce weapons-usable nuclear material – will be fundamental to achieving that objective. Indeed, a strong case can be made that a strengthened nonproliferation regime, along with strong safety and security performance, are fundamental to enabling nuclear energy to grow on the scale that would be required for it to contribute significantly to mitigating climate change.[28]

To prevent nuclear terrorism, the United States should seek to minimize and ultimately eliminate the civil use of HEU and separated plutonium, and to ensure that all stocks of these materials worldwide have security and accounting measures that effectively protect them against plausible outsider and insider threats. To reduce the danger of nuclear proliferation and lay the foundation for the long-term goal of eliminating most or all of the world's nuclear weapons, the United States should seek a world in which:

- As few states as possible operate enrichment or reprocessing facilities;
- Those facilities are subject to the most effective practicable international inspection;
- Every state that operates such facilities is subject to the broader national-level monitoring and reporting called for by the Additional Protocol, and perhaps additional transparency measures;
- Every state that operates such facilities has put in place highly effective export controls, controls on classified information, and other measures to prevent leakage and black-market transfers of sensitive nuclear technology; and
- Ultimately, all enrichment and reprocessing facilities are under multinational or international, rather than purely national, control and staffing.

None of this can be achieved by attempting to dictate to other countries; rather, it will have to be achieved by structuring incentives for countries to cooperate in their mutual interest. The choices the United States makes about the back end of the nuclear fuel cycle in the next few years can affect each of these points.

Minimizing the civil use of plutonium and HEU, and ensuring effective security

[27] For compilations of recommended steps for the broader problem of nuclear nonproliferation, see, for example, George Perkovich et al., *Universal Compliance: A Strategy for Nuclear Security* (Washington, D.C.: Carnegie Endowment for International Peace, 2005), http://www.carnegieendowment.org/files/UC2.FINAL3.pdf (accessed 10 December 2009); Weapons of Mass Destruction Commission, Hans Blix, chairman, *Weapons of Terror: Freeing the World of Nuclear, Biological, and Chemical Arms* (Stockholm: Weapons of Mass Destruction Commission, 2006), http://wmdcommission.org/files/Weapons_of_Terror.pdf (accessed 9 February 2009); and International Commission on Nuclear Non-Proliferation and Disarmament, Gareth Evans and Yoriko Kawaguchi, co-chairs, *Eliminating Nuclear Threats: A Practical Agenda for Global Policymakers* (Canberra/Tokyo: International Commission on Nuclear Non-Proliferation and Disarmament, November 2009), http://www.icnnd.org/reference/reports/ent/pdf/ICNND_Report-EliminatingNuclearThreats.pdf (accessed 20 May 2010).

[28] Matthew Bunn and Martin Malin, "Enabling a Nuclear Revival – And Managing Its Risks," *Innovations: Technology, Governance, Globalization*, Vol. 4, Issue 4, (Fall 2009), pp. 173-191.

The Obama administration deserves credit for dramatically elevating the level of international political attention focused on securing nuclear stockpiles around the world. The United States and other interested governments need to hit the ground running in turning the words from the nuclear security summit into real nuclear security improvements on the ground. There is a great deal to be done if the goal of providing effective security for all stockpiles of nuclear weapons and weapons-usable nuclear materials worldwide within four years is to be achieved.[29] The U.S. government should undertake:

- A broad range of measures, from detailed threat briefings to nuclear terrorism simulations and exercises, to convince policymakers around the world that nuclear terrorism is a real and urgent threat to their countries' security, requiring them to devote more of their time and resources to reduce the risk;
- A broader approach to consolidating nuclear weapons and materials in fewer locations, so as to achieve higher security at lower cost, that focuses on consolidating a more comprehensive set of nuclear stockpiles, using a wider range of incentives and policy tools;
- A broader approach to upgrading security for nuclear weapons and materials, that seeks to achieve improvements to higher standards in more countries, that focuses not only on U.S.-sponsored upgrades but also on convincing countries to undertake substantial improvements themselves, and that includes an intense focus on crucial but difficult-to-measure areas such as effective regulation, sustainability, and security culture.

As part of this broad effort, the United States should be clear that it does not believe separating weapons-usable plutonium from spent fuel is a good idea. I recommend that the commission call on the Obama administration to reiterate that the United States does not itself reprocess for either civilian power generation or weapons purposes, and does not support reprocessing elsewhere, particularly in regions of tension, though it will not interfere in the established fuel cycle programs of states with strong nonproliferation credentials. This would effectively continue the message the United States began sending in 1976: "reprocessing is unnecessary; we, the country with the world's largest nuclear fleet, are not doing it, and you do not need to either." Contrary to what is often said, this policy has been highly successful: no countries have built civilian reprocessing plants that were not already reprocessing or building such facilities as of 1976, three decades ago, and roughly a dozen countries have stopped reprocessing since then.[30] In the Bush administration, the U.S. message changed to "reprocessing is essential to the future of nuclear energy, but we will keep the technology away from all but a few states."[31] That message – effectively attempting to divide the world again into

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[29] See Matthew Bunn, *Securing the Bomb 2010: Securing All Nuclear Materials in Four Years* (Cambridge, Mass.: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, April 2010), http://www.nti.org/securingthebomb (accessed 20 May 2010).

[30] The major commercial reprocessing facilities in the world are in France, the United Kingdom, Russia, and Japan. The first three already had reprocessing well underway in 1976, and the Japanese Tokai plant was well advanced at that time. China and India both have some reprocessing activities, but both had reprocessing technology already in 1976. North Korea has established a reprocessing plant since 1976, but it is entirely for military purposes, not a commercial plant that might be influenced by U.S. policy on commercial reprocessing. Since 1976, a number of countries that were previously pursuing reprocessing (such as Germany and Sweden, among others) have joined the United States in abandoning reprocessing in favor of direct disposal. In general, the poor economics of reprocessing have driven decisions more than U.S. policy.

[31] This formulation is adapted from Frank von Hippel, "GNEP and the U.S. Spent Fuel Problem," congressional

"haves" and "have nots" – is not likely to be an acceptable and sustainable approach for the long haul. Having other countries pursue UREX+ rather than PUREX would be only a modest improvement, as once a country had a team of people with experience in chemically processing intensely radioactive spent nuclear fuel and a facility for doing so, this expertise and infrastructure could be adapted very rapidly to separate pure plutonium for weapons – much as countries with enrichment could readily switch from producing low-enriched uranium to producing highly enriched uranium (HEU) should they choose to do so.

The United States should then take some specific actions to support this policy:

- Redouble efforts to negotiate a verified fissile material cutoff treaty (FMCT), including considering other venues if the Conference on Disarmament proves unable to move forward;
- Seek to complete the accord with Russia on a 20-year moratorium on plutonium separation that was almost finished at the end of the Clinton administration;
- Work with countries that are now reprocessing to seek means to begin reducing the vast stockpiles of civilian plutonium that have accumulated over the years; and
- As part of the nuclear security dialogue with China and India, seek to convince them that their nuclear energy programs, like ours, would be better served by relying on storage of spent fuel and R&D on more advanced technologies for both open and closed fuel cycles than on a near-term shift to large-scale plutonium breeder reactors and reprocessing (which could result in many tons of plutonium being processed and shipped from place to place every year in countries whose regulation and enforcement have sometimes raised questions in the past).

South Korea, currently the only country that does not have a reprocessing plant that is interested in establishing one, poses a particularly difficult challenge. The U.S.-South Korean nuclear cooperation agreement is up for renegotiation, and South Korea is seeking U.S. approval for pyroprocessing in South Korea. On the one hand, South Korea today is a member in good standing of the Nonproliferation Treaty (NPT), with the Additional Protocol in place, it has significant political problems in providing adequate storage for its spent nuclear fuel, it is pursuing a technology that some see as significantly more proliferation-resistant than traditional PUREX reprocessing, and it has a legitimate complaint that it would be unfair for the United States to give blanket approval to reprocessing in Japan and even in India, a state outside of the NPT with major nuclear facilities not subject to safeguards, but deny South Korea approval for pyroprocessing. On the other hand, South Korea is a state that has had a secret reprocessing-based nuclear weapons program in the past; was quite recently found to have carried out undeclared nuclear activities (though those issues are now largely resolved); and has an agreement with North Korea prohibiting enrichment and reprocessing on the Korean peninsula. Although North Korea has been in clear violation of that agreement for years, a South Korean move away from that denuclearization accord would likely make elimination of North Korea's nuclear weapons program more difficult to achieve. There can be little doubt that South Korea is in a region of tension. I recommend that the United States work actively with South Korea to help resolve South Korea's spent fuel storage problems – including, for example, international

staff briefing, 10 March 2006.

(or U.S.) review and certification of the safety of the proposed storage facilities – but not move in the near term to approve pyroprocessing in South Korea.[32]

Limiting the spread of enrichment and reprocessing facilities

The United States should continue to seek to limit the spread of enrichment and reprocessing facilities to additional states, through incentives-based approaches. The first step, as noted above, should be to make clear that we do not reprocess ourselves and do not encourage others to do so.

The next step should be to complete the discussions now underway in the Nuclear Suppliers Group on criteria-based constraints on export of enrichment and reprocessing technologies – while simultaneously working to convince potential suppliers to continue the kind of restraint they have exercised in recent years. (No member of the group has authorized an export of enrichment or reprocessing technology to a state that did not already have such technology for decades.)

Next, the United States should continue to work with other countries to establish incentives that encourage countries to rely on international nuclear fuel supply rather than bothering with the large investments needed to build their own enrichment and reprocessing facilities. Measures such as an IAEA fuel bank and joint fuel supply assurances from the major suppliers can increase countries' confidence that they can rely on international fuel supply without worrying about interruptions of low-enriched uranium supply – and help focus the international spotlight on the motives of countries that nevertheless move ahead with uranium enrichment programs.

But the reality is that the existing commercial market already provides fuel supplies that most countries consider highly reliable, so these additional assurances are likely to have a modest overall effect.[33] An offer to manage countries' spent fuel – so that countries could make use of nuclear energy without having to establish their own waste repositories – could be a more powerful incentive for countries to rely on international fuel supply. Hence, the United States should actively work with other countries to develop concepts such as fuel leasing (providing fresh fuel with a promise to take back the irradiated fuel), reactor leasing, and international or regional repositories. Russia already has legislation on the books that allows it to take back spent fuel that originated in Russia, and it has such a contract in place with Iran, among others – which the United States has complimented as a step in the right direction.

As part of that overall effort, with several countries potentially participating as recipients of spent fuel, the United States should be willing to take limited quantities of spent power reactor fuel from other countries – as we import spent research reactor fuel today – when it is in U.S. national security interests to do so. I believe the commission should recommend, as part of a broad package of amendments to the Nuclear Waste Policy Act, an amendment that would allow the United States to import foreign spent power reactor fuel, perhaps limited to no more than to

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[32] For discussion of this issue, see Frank N. von Hippel, "South Korean Reprocessing: An Unnecessary Threat to the Nonproliferation Regime," *Arms Control Today,* March 2010, http://www.armscontrol.org/act/2010_03/VonHippel (accessed 20 May 2010).

[33] For discussion of these concepts, see, for example, U.S. Committee on Internationalization of the Nuclear Fuel Cycle, National Academy of Sciences and National Research Council, and Russian Committee on Internationalization of the Nuclear Fuel Cycle, Russian Academy of Sciences, *Internationalization of the Nuclear Fuel Cycle: Goals, Strategies, and Challenges* (Washington, D.C.: National Academy Press, 2008).

5-15% of the total amount of nuclear waste the United States will need to manage in any case, when the administration concludes, with Congressional review, that it is in the U.S. national security interest to do so. This could become an important part of the effort to stem the spread of enrichment and reprocessing facilities around the world.

Effective safeguards for all enrichment and reprocessing facilities

Ultimately, all reprocessing and enrichment facilities should be subject to the most effective practicable international inspections, whether they are in nuclear weapon states or non-nuclear-weapon states. This will be an essential part of a verifiable FMCT, and will be even more essential if the world is ultimately going to move toward the long-run goal of a world free of nuclear weapons. Currently four new enrichment plants are planned in the United States. All of these will be *eligible* for international safeguards, but because the IAEA has little money and few inspectors, it is likely that none of them will actually be placed under safeguards. (DOE could pay the agency's costs to safeguard such facilities, as it has in the case of safeguarding excess fissile material in the United States, but so far this has been considered a modest priority for scarce DOE nonproliferation budgets.) I recommend that the Commission call for new legislation under which any firm or agency proposing to build and operate a new enrichment or reprocessing facilities in the United States, whether at commercial scale or demonstration scale, would be required, as a condition of their license, to provide sufficient funds and personnel to the IAEA to enable effective safeguards.[34] As the costs of safeguards inspections are very modest (by commercial standards) this would be a minor additional cost to the firms, with potentially substantial nonproliferation benefits.

In addition, the United States should work to ensure that the principle of "safeguards by design" is followed in the construction of all new enrichment and reprocessing facilities worldwide, so that these facilities are designed to facilitate highly effective inspection and security measures at modest cost. Demonstration that as-effective-as-reasonably-practicable safeguards and security measures have been designed in from the outset should also be a license condition in the United States, and the U.S. government should try to convince other governments to take a similar approach. This will make it possible to develop and demonstrate advanced safeguards approaches and technologies in the United States that can then be implemented in other countries as well.

Effective national safeguards for all countries operating such facilities

Today, international safeguards have moved from an exclusive focus on monitoring at declared facilities to a "state-level approach" that seeks to develop a coherent picture of all the nuclear activities of a state, to increase the chance that activities associated with a covert nuclear facility would be noticed. The United States should seek a world in which all countries operating enrichment or reprocessing facilities accept the broader state-level inspections and reporting called for under the Additional Protocol, and should seek to develop additional incentives and disincentives to convince states to accept the protocol. (At present, the principal "outliers" – states with enrichment or reprocessing without an Additional Protocol in place – are Iran, North Korea, Brazil, and Argentina.)

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[34] Money and people are fungible, so it would in general not be personnel provided by these firms who would be safeguarding their firms' facilities; rather, these individuals would free up other Agency staff who could provide safeguards at these facilities.

Effective export controls and other measures to prevent technology leakage

The global black-market nuclear technology led by Pakistan's A.Q. Khan revealed major weaknesses in controls over sensitive nuclear technologies around the world. The United States should work with other countries to strengthen export controls; ensure that companies working with sensitive technologies know what technologies might pose a threat and take a proactive approach, in cooperation with governments, to ensuring that their technologies are controlled; beef up criminal penalties and their enforcement; address corruption in the nuclear industry and among customs and border control officials; expand police and intelligence cooperation; and more. This is an urgent agenda, but one that will require considerable effort to overcome the political hurdles to progress, as these issues also relate to international trade and economic development.

Multinational or international control and staffing

Finally, as the world moves toward more and more nuclear energy and fewer and fewer nuclear weapons, having individual countries in sole control of enrichment or reprocessing facilities capable of producing thousands of weapons' worth of nuclear material each year will be increasingly problematic. Step by step, the United States should seek to move toward a world in which enrichment and reprocessing facilities are under multinational or international control and staffing. As former IAEA Director General Mohammed ElBaradei once put it, the long-term goal "should be to bring the entire fuel cycle, including waste disposal, under multinational control, so that no one country has the exclusive capability to produce the material for nuclear weapons."[35]

The political barriers to a country using a facility to produce weapons material would be substantially higher if the facility were multinationally owned and staffed, and a 24/7 international operating staff would provide high confidence that any such effort, or any significant diversion from the facility, would be quickly noticed. Moreover, as most countries do not have unlimited numbers of people qualified to work on enrichment or reprocessing, an international staff might also notice if significant numbers of host-country experts they had been working with began disappearing for weeks at a time to work on a covert facility using similar technology. There would also be proliferation risks from such an approach, particularly related to possible spread of sensitive knowledge about the facility to the multinational staff; the staff should be limited to individuals who are able to obtain relevant security clearances from countries that possess the technology used at the facility. More study is needed of the many different specific models of multinational or international facilities that have been envisioned, and the specific benefits and risks that might be associated with each.

But there is also a need for near-term action. Four new enrichment plants are currently planned in the United States. Some of these, such as the facilities in which URENCO or Areva are major partners, are already envisioned as facilities that would have a substantial degree of multinational ownership. I believe Congress should eliminate the requirement in U.S. law to maintain a U.S.-owned enrichment capacity – which may have been relevant when we needed uranium enrichment for military purposes, but is no longer relevant – and that the United States

[35] Mohammed ElBaradei, "Reviving Nuclear Disarmament," Oslo, Norway, 26 February 2008, http://www.iaea.org/NewsCenter/Statements/2008/ebsp2008n002.html (accessed 20 May 2010).

should adopt a policy that all new enrichment facilities in the United States will be subject to multinational ownership and control, working with other countries to do the same.

6. *It is worth investing in research and development on improved approaches to both open and closed fuel cycles.*

Someday, recycling technologies may be developed which are substantially cheaper and more proliferation-resistant than those now available. R&D should be pursued to explore such possibilities. In parallel, there should also be R&D on improved approaches to direct disposal. This R&D should include a much broader set of reactor and spent fuel processing technologies than were pursued during the Bush administration; it would be a mistake to down-select and focus only on technologies that could be deployed soon, when other technologies may have more long-term promise.[36] As improved recycling and once-through technologies develop, we should regularly re-examine which of them appear to offer the best combination of cost, safety, security, proliferation-resistance, and sustainability. At the same time, we should not allow an expansion of nuclear R&D to overwhelm R&D on other promising energy technologies: the United States urgently needs to undertake expanded investments in a wide range of energy R&D, along with appropriate support for demonstration and deployment of low-carbon energy technologies.[37]

In particular, the U.S. nuclear energy R&D program should include efforts focused on:

- Further improvements in modeling and simulation of nuclear reactors and fuel cycle systems (making it possible to explore new ideas more rapidly, at lower cost, and with higher confidence, and to make sure the larger investments required for experiments and demonstrations are targeted on the most promising approaches);
- A range of spent fuel processing and fuel fabrication technologies judged to have significant promise in overcoming the proliferation an cost liabilities of existing systems (which should be explored as *systems* with potential reactor technologies);
- A range of both fast and thermal reactor systems, making use of both open and closed fuel cycles, including in particular systems that may offer opportunities for reductions in cost, extension of uranium resources, or minimization of wastes without increasing proliferation risks;
- Concepts that may make it possible to extend uranium resources substantially without substantially separating plutonium or U-233 from spent fuel, including concepts for "breeding in place" without reprocessing (such as the "Terrapower" concept and several others), and concepts where only a small portion of the fission products are removed on a frequent basis, leaving the fissile material in the core, such as the molten salt reactor;
- Improved approaches to permanent disposal of spent fuel and nuclear wastes, including not only different mined repository concepts but concepts for deep borehole disposal as well;

[36] For a discussion of R&D that should be pursued on improved once-through options, see Deutch, Moniz, et al., *The Future of Nuclear Power*.

[37] For a recent update, see Laura Diaz Anadon, Matthew Bunn, Gabriel Chan, Melissa Chan, Kelly Sims Gallagher, Charles Jones, Ruud Kempener, Audrey Lee, and Venkatesh Narayanamurti, *DOE FY 2011 Budget Request for Energy Research, Development, Demonstration, and Deployment: Analysis and Recommendations* (Cambridge, Mass.: Energy Technology Innovation Policy, Harvard Kennedy School, April 2010).

- Small, factory-built reactors with high levels of inherent safety and minimal staffing requirements, possibly with sealed cores, which might offer the opportunity for a broad deployment of nuclear energy with minimal proliferation risk;
- An in-depth global assessment of the quantity of uranium likely to be available at different costs as technology and geologic understanding advance in the future;
- Advanced technologies and procedures for international safeguards; and
- Advanced technologies and procedures for physical protection, material control, and material accounting.[38]

A major issue with respect to nuclear R&D is how to move from R&D to commercial application. Nuclear energy is often an inherently large-scale technology, making demonstrations of new technologies expensive and difficult. The intersection between what the federal government should support and what the private sector should do itself, and the potential for partnerships among them, has not been well explored. Similarly, despite international efforts such as the Generation IV International Forum and the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles, the question of how countries pursuing similar nuclear technologies can best pool their efforts still requires additional work.

I believe the Commission should support R&D in broad areas such as these, but should not attempt to lay out a specific R&D plan, leaving that to R&D program managers.

Recommendations

This Commission has a major responsibility – and a major opportunity – to lay out a politically sustainable path out of the morass that characterizes U.S. nuclear waste management policy today. A successful path must include a new approach to building public trust and siting necessary facilities, based on voluntarism, openness, and democracy. Beyond that, I recommend that we follow the advice of the bipartisan National Commission on Energy Policy, which concluded that the United States should:

- Continue its moratorium on reprocessing;
- Expand interim spent fuel storage capacities, including through legislation that would require the Department of Energy to establish at least limited consolidated national or regional storage facilities;
- Amend the Nuclear Waste Policy Act to make clear that interim storage and federal responsibility for waste disposal are sufficient to satisfy the Nuclear Regulatory Commission's waste confidence requirement;
- Amend the act to require the Secretary of Energy to take possession of and/or remove fuel from decommissioned reactor sites;
- Proceed "with all deliberate speed" toward opening a permanent waste repository; and

[38] See, for example, Nuclear Energy Study Group, American Physical Society Panel on Public Affairs, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk* (Washington, D.C.: American Physical Society, May 2005), http://www.aps.org/policy/reports/popa-reports/proliferation-resistance/upload/proliferation.pdf (accessed 20 May 2010).

- Continue nuclear energy research and development, including on advanced fuel cycle approaches that might overcome the huge disadvantages of traditional approaches to reprocessing.

At the same time, the U.S. government should redouble its efforts to keep nuclear weapons and the materials and technologies needed to make them out of the hands of terrorists and hostile states, including through ensuring effective security for all nuclear weapons and weapons-usable nuclear materials worldwide, limiting the spread of enrichment and reprocessing facilities, and ensuring that those facilities that do exist are under the strictest practicable control, ultimately including multinational control and staffing. As part of that effort, I believe the United States should support efforts to establish multinational spent fuel storage and disposal facilities and fuel leasing approaches, so that every country that pursues nuclear energy will not need its own repository. I would hope that in discussions of amendments to the Nuclear Waste Policy Act, we would hold open the option for importing at least limited quantities of spent fuel from other countries where doing so would serve U.S. national security and climate security interests.

I would be happy to take your questions.